

High-momentum protons in Ca isotopes

Julian Kahlbow

SRC-EMC Workshop, June 8th 2026

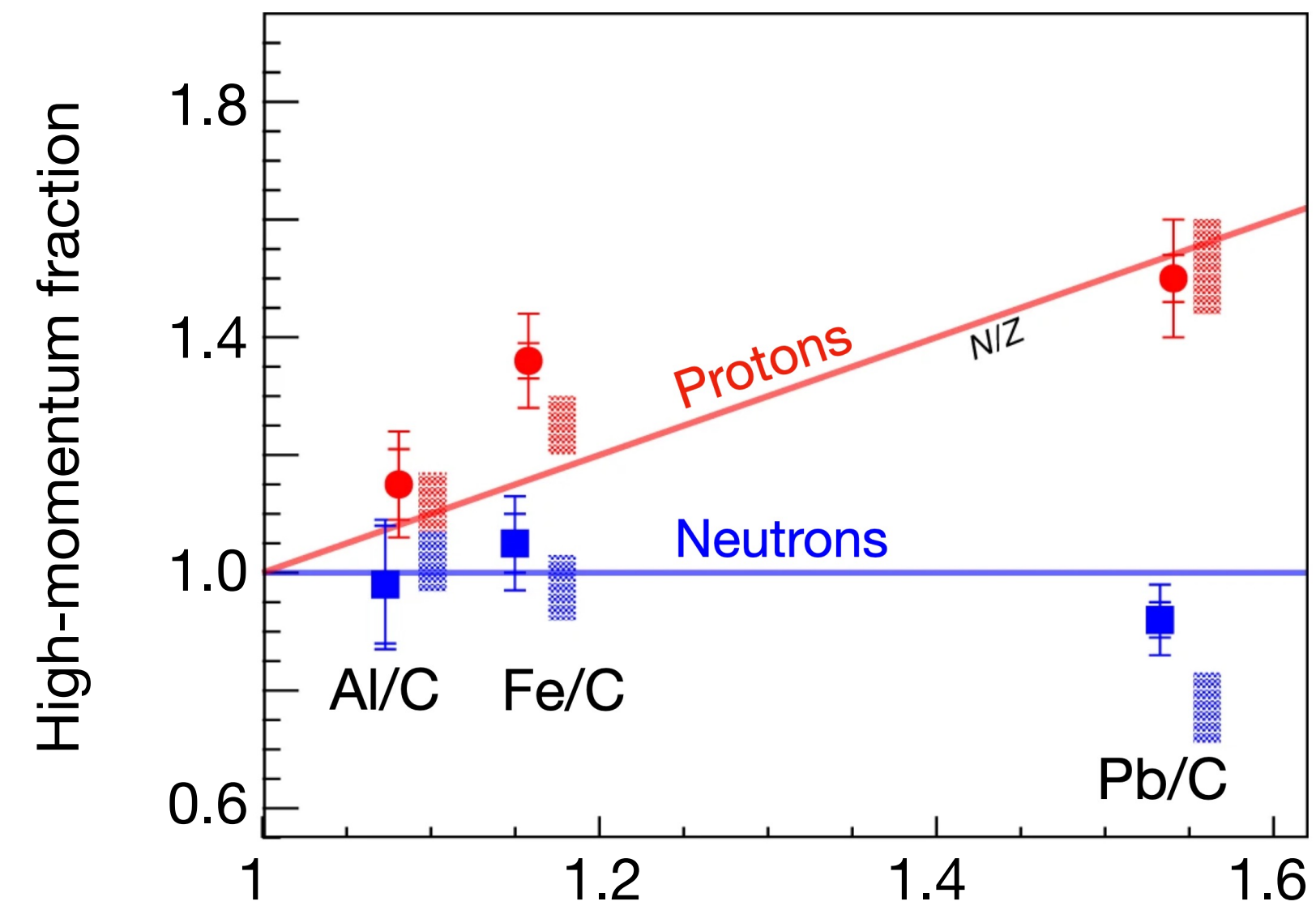


BERKELEY LAB

SRC behavior in asymmetric nuclei

2018

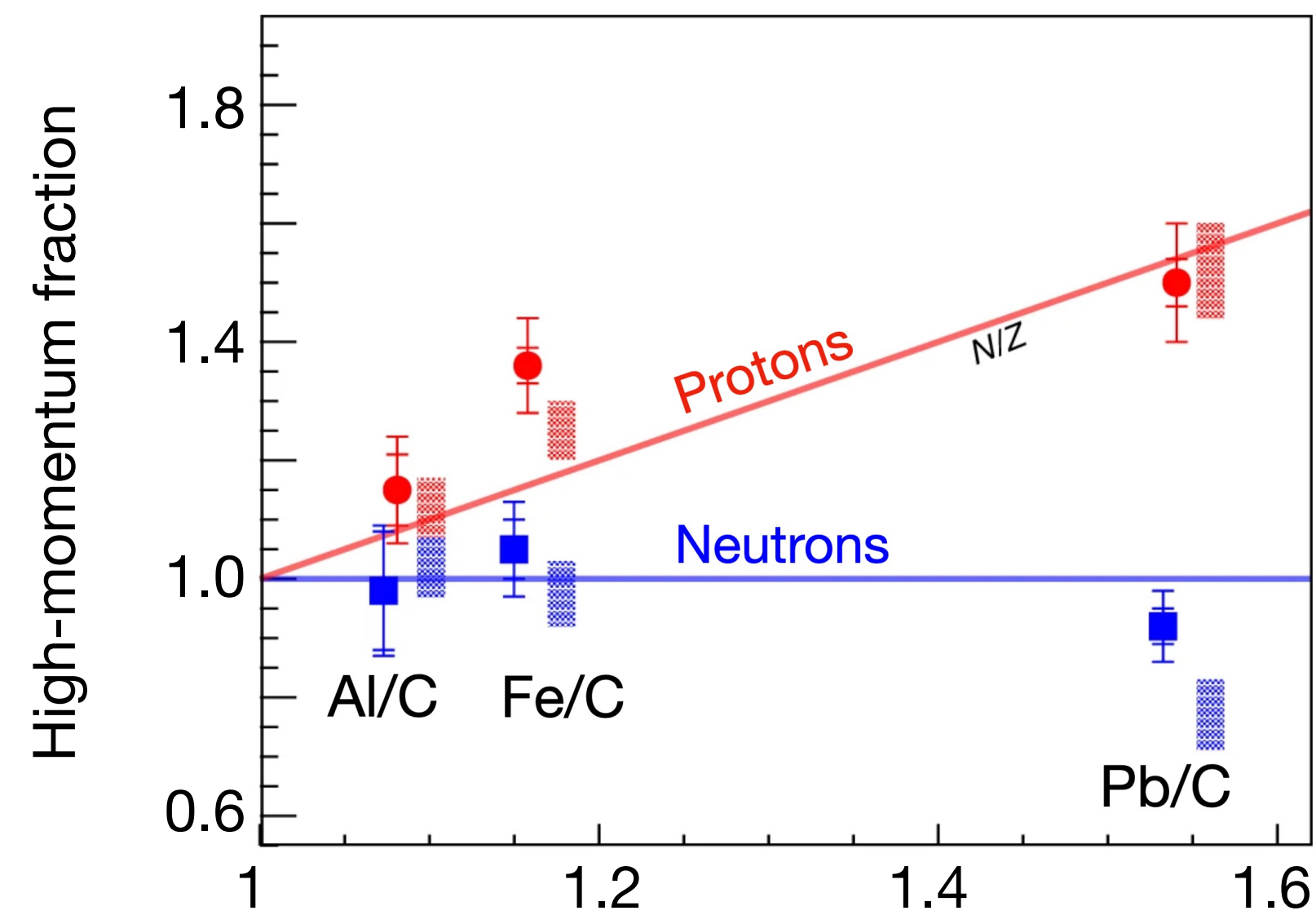
M. Duer et al. (CLAS), Nature 560 (2018)



SRC behavior in asymmetric nuclei

2018

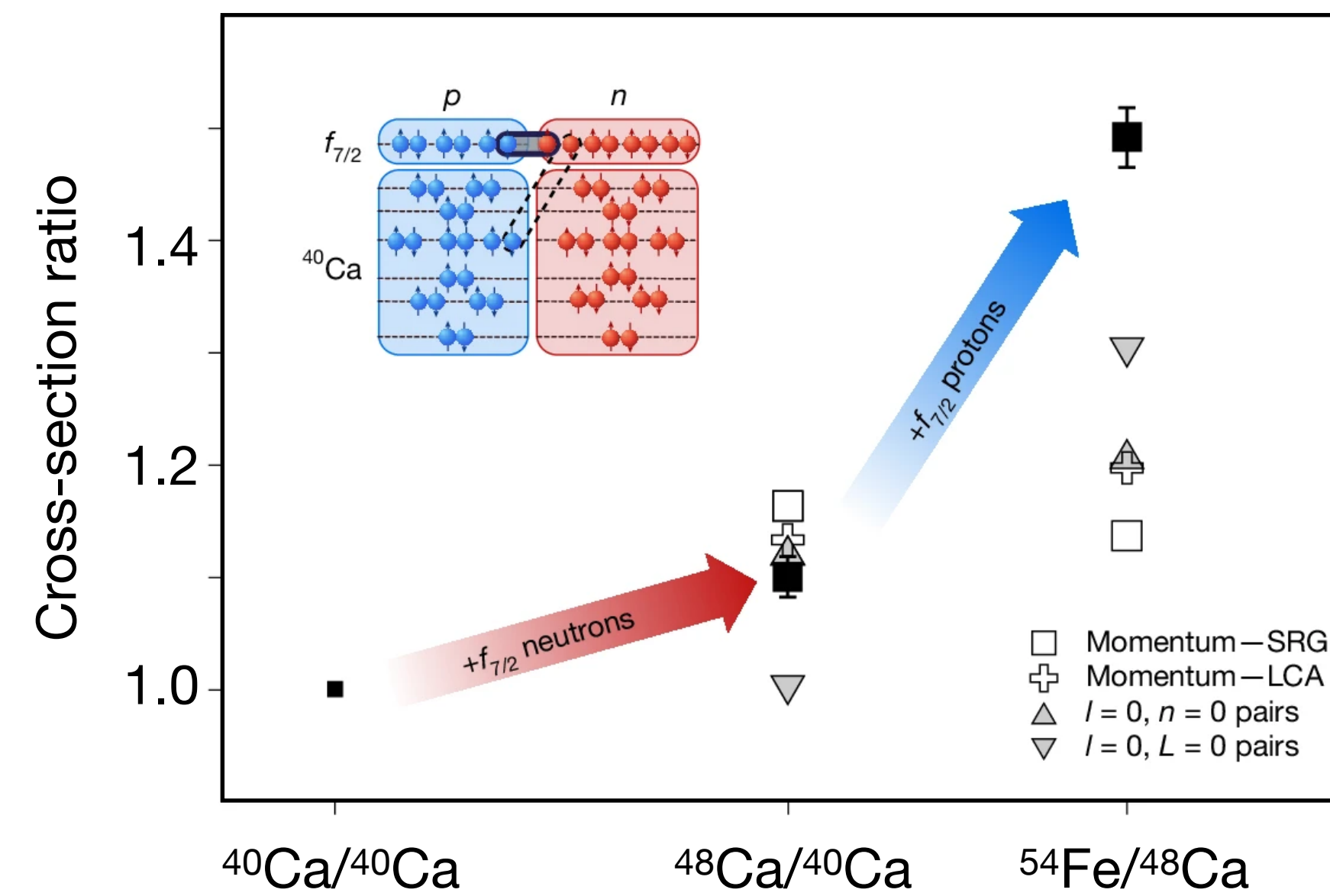
M. Duer et al. (CLAS), Nature 560 (2018)



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2026

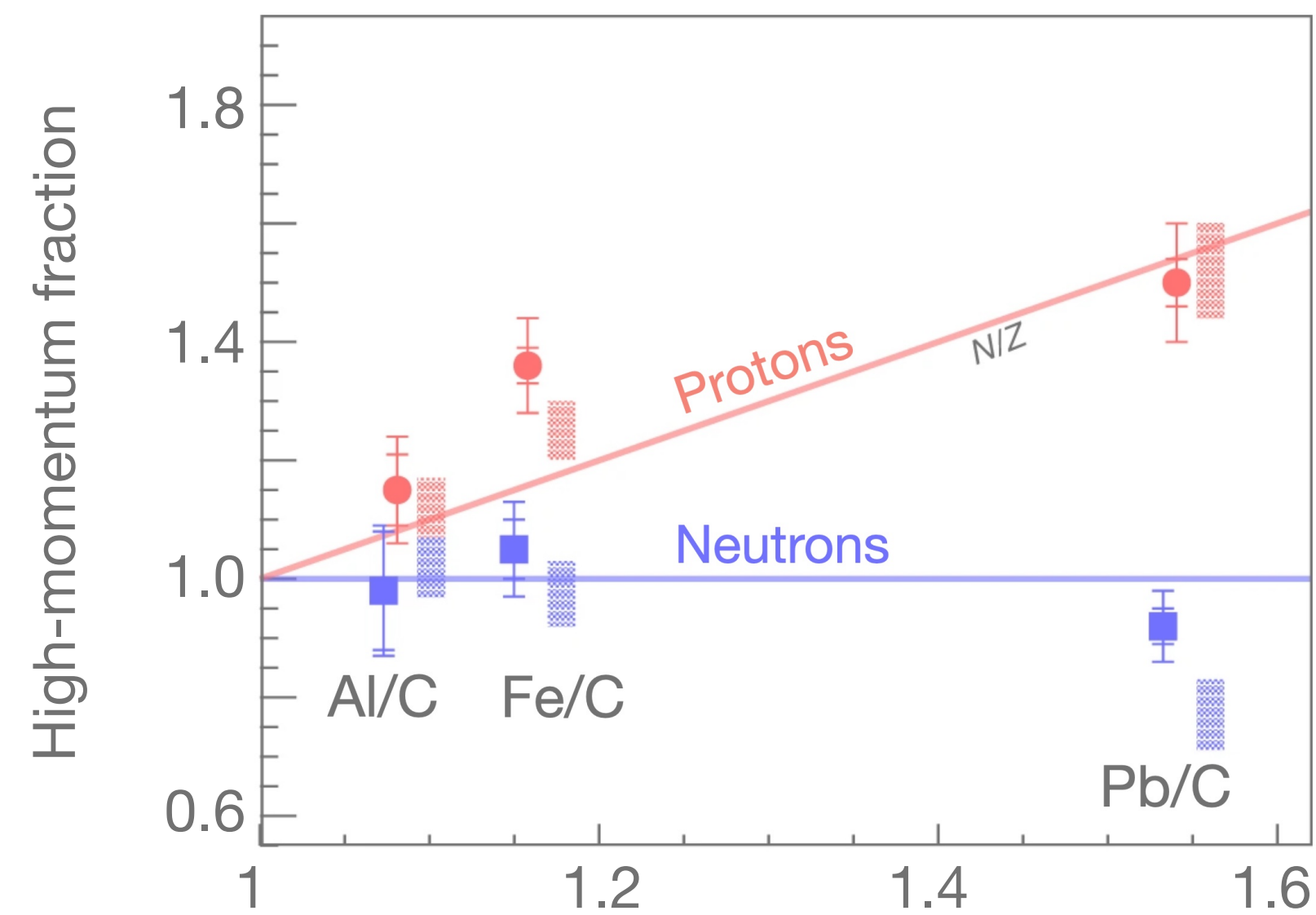
D. Nguyen et al., Nature (2026)



SRC behavior in asymmetric nuclei

2018

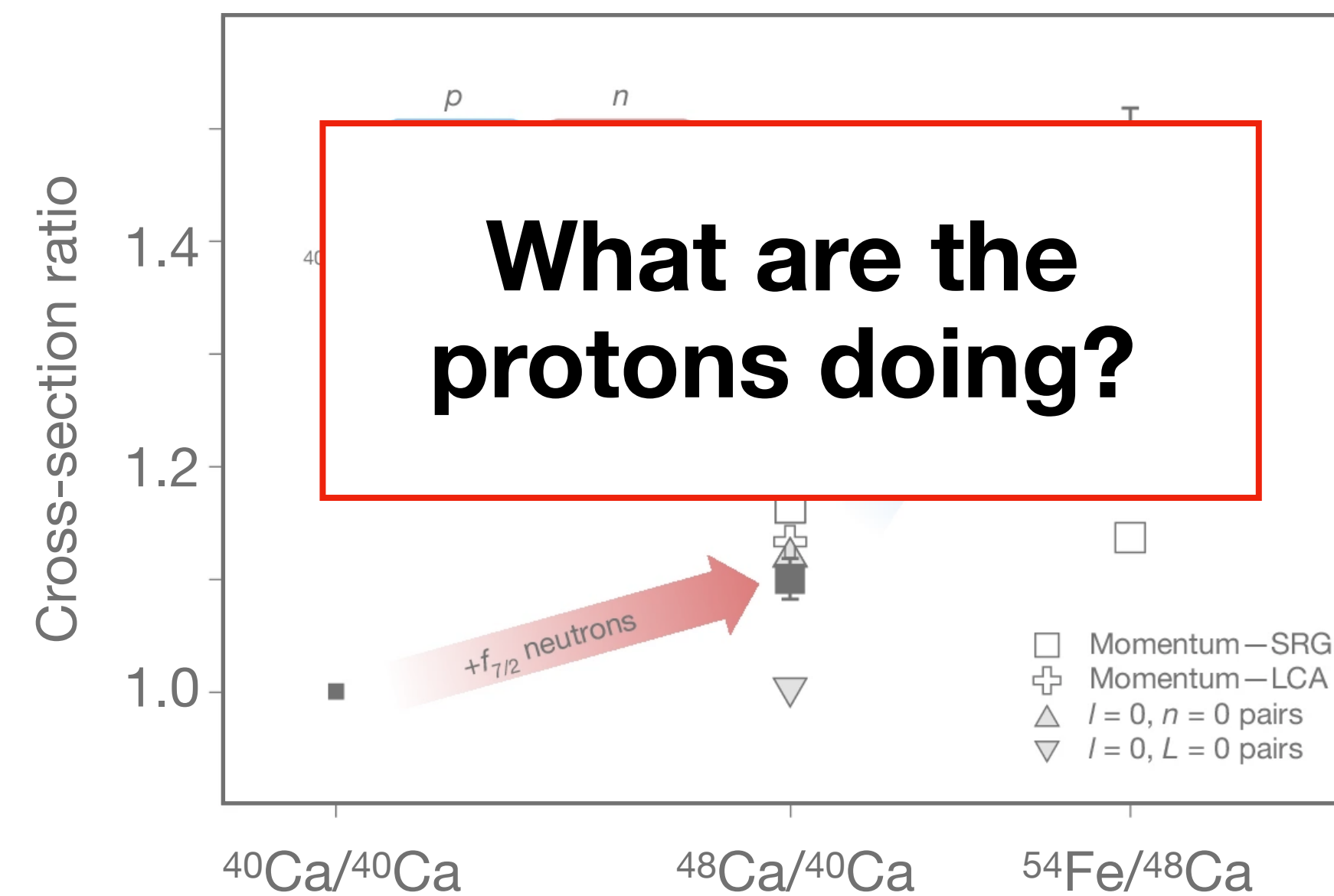
M. Duer et al. (CLAS), Nature 560 (2018)



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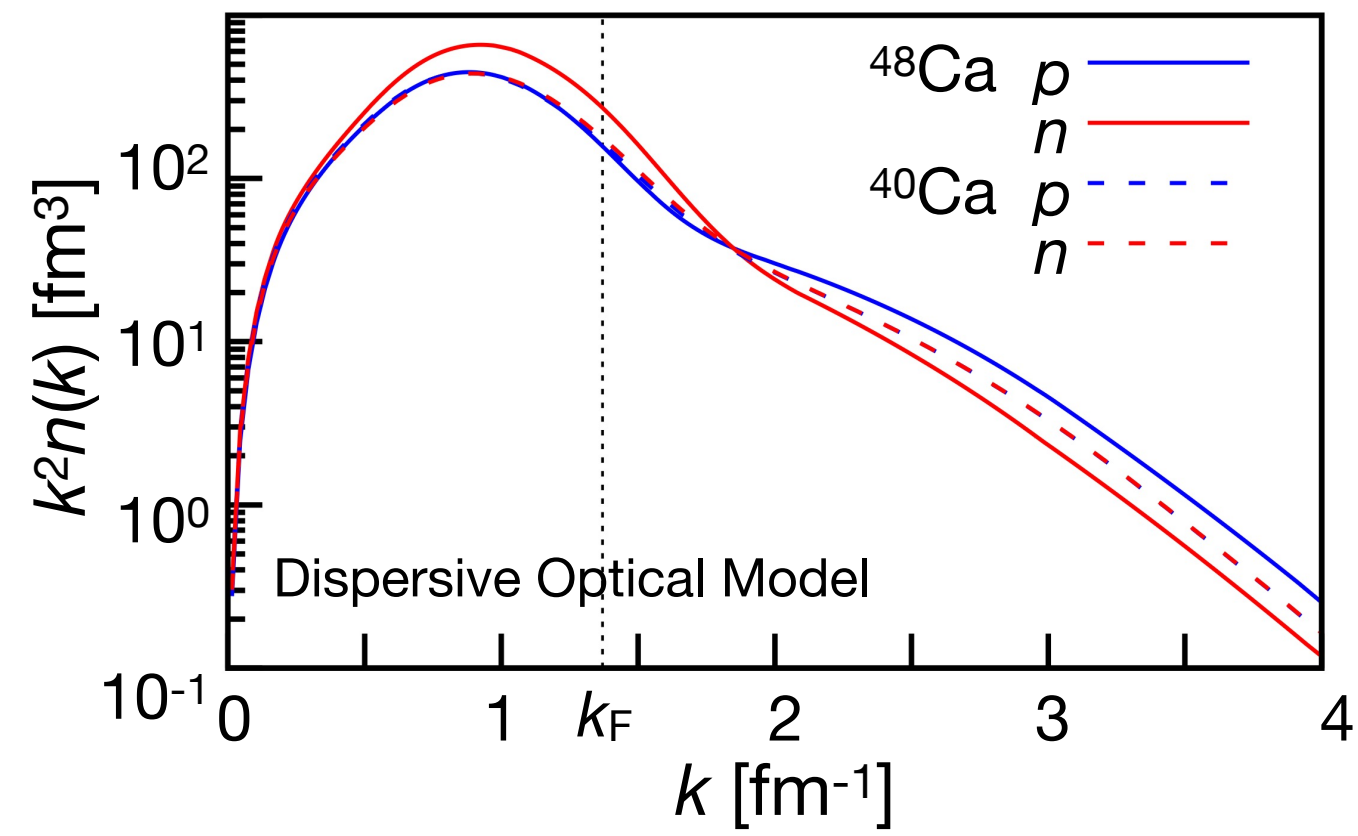
2026

D. Nguyen et al., Nature (2026)



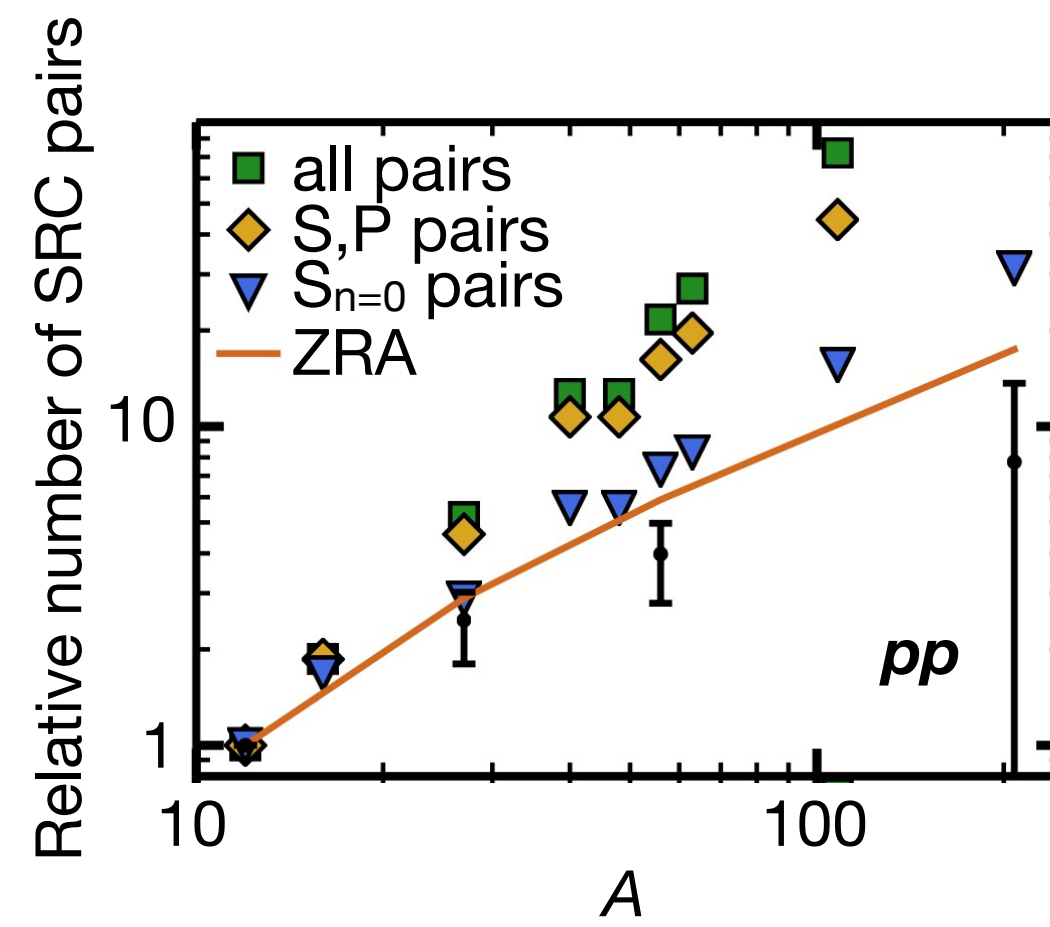
Theory predictions

M.C. Atkinson, W.H. Dickhoff, PLB 798 (2019)

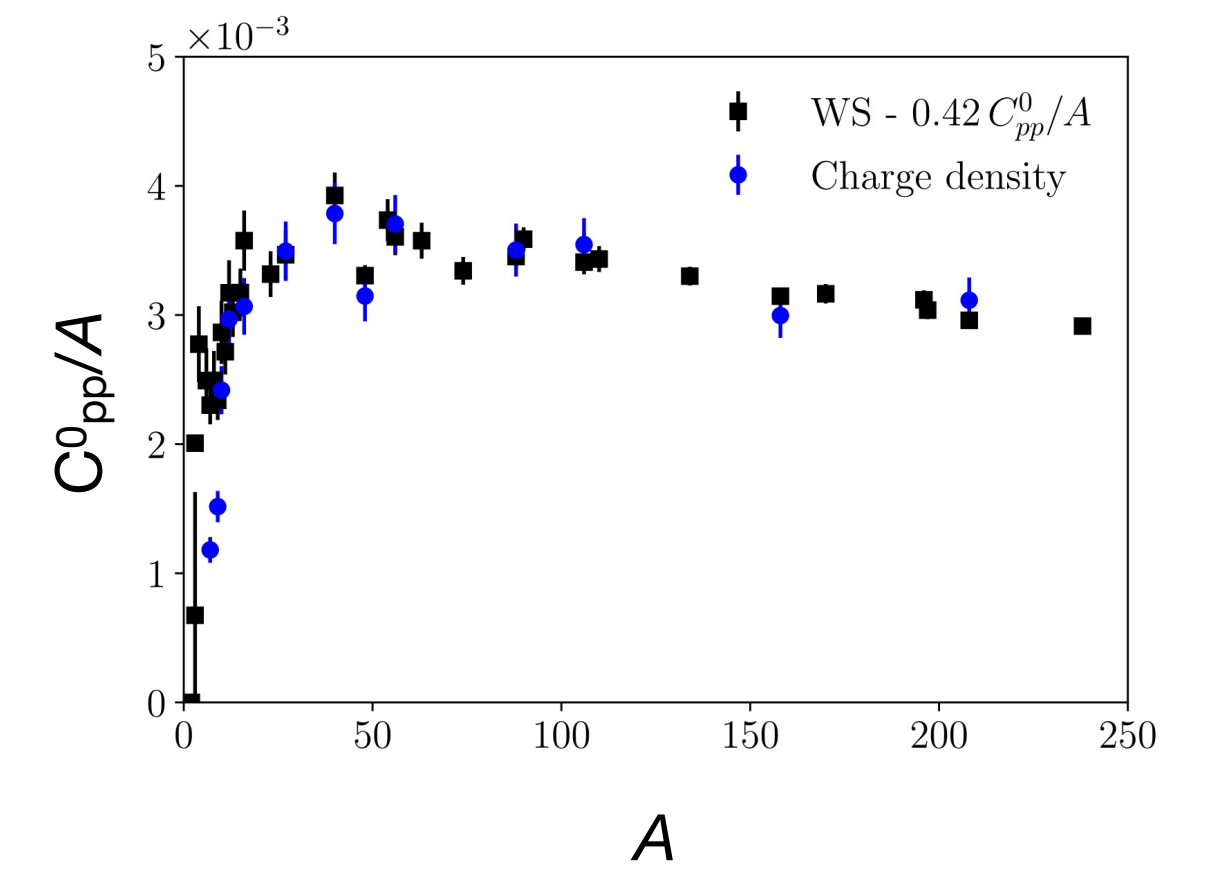


→ more high-momentum proton content in $^{48}\text{Ca}/^{40}\text{Ca}$

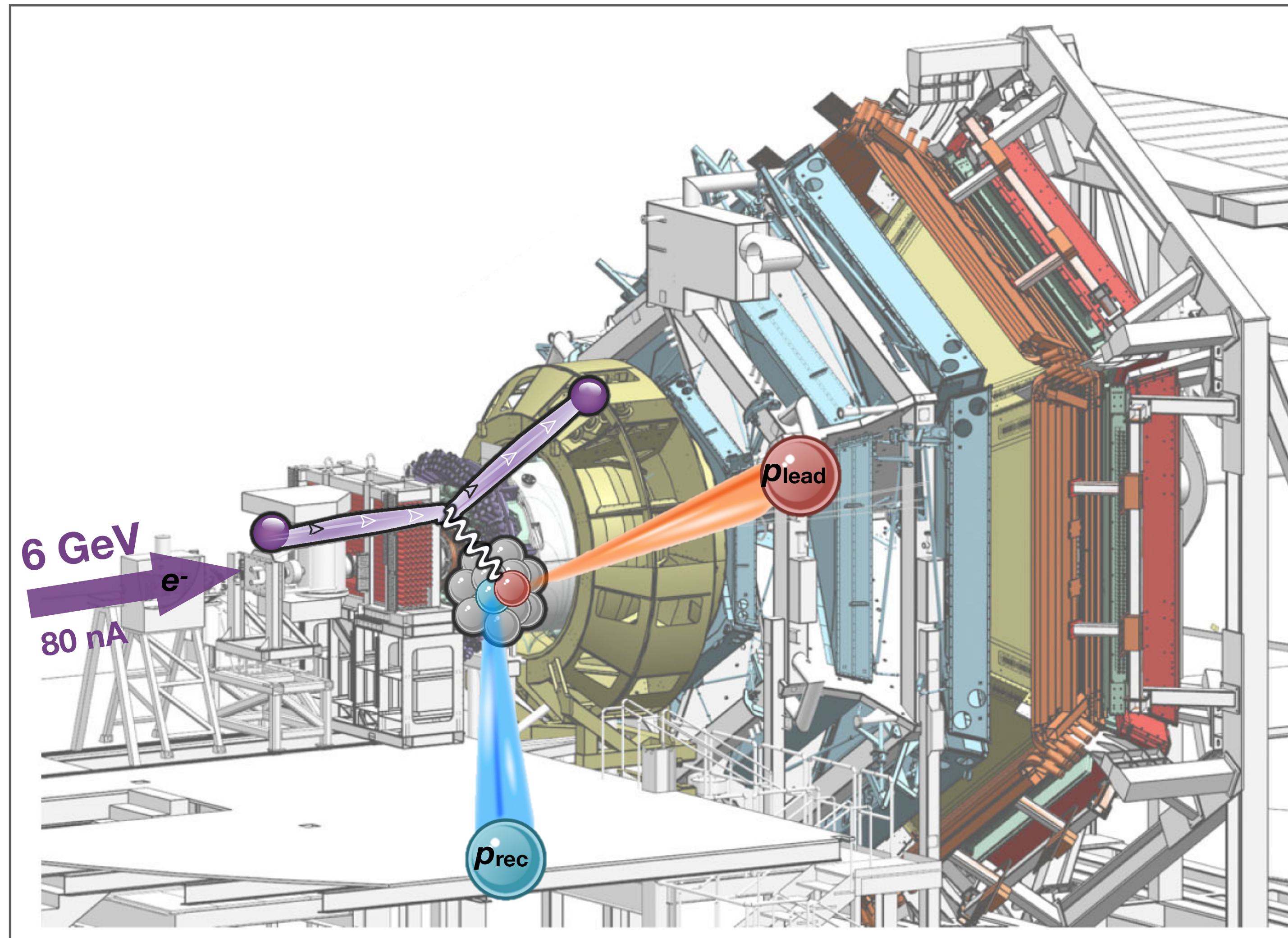
C. Colle et al., PRC 92 (2015)



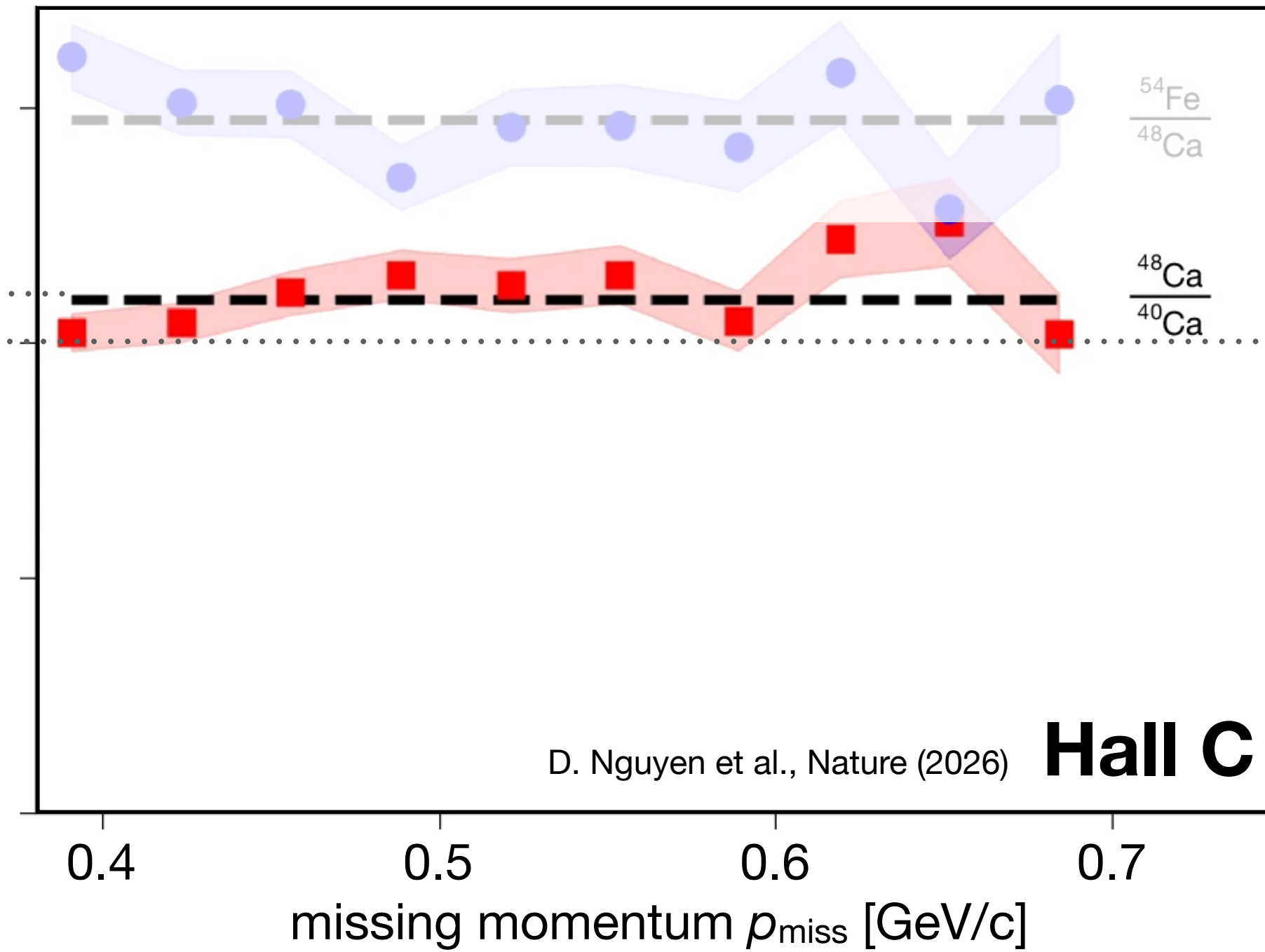
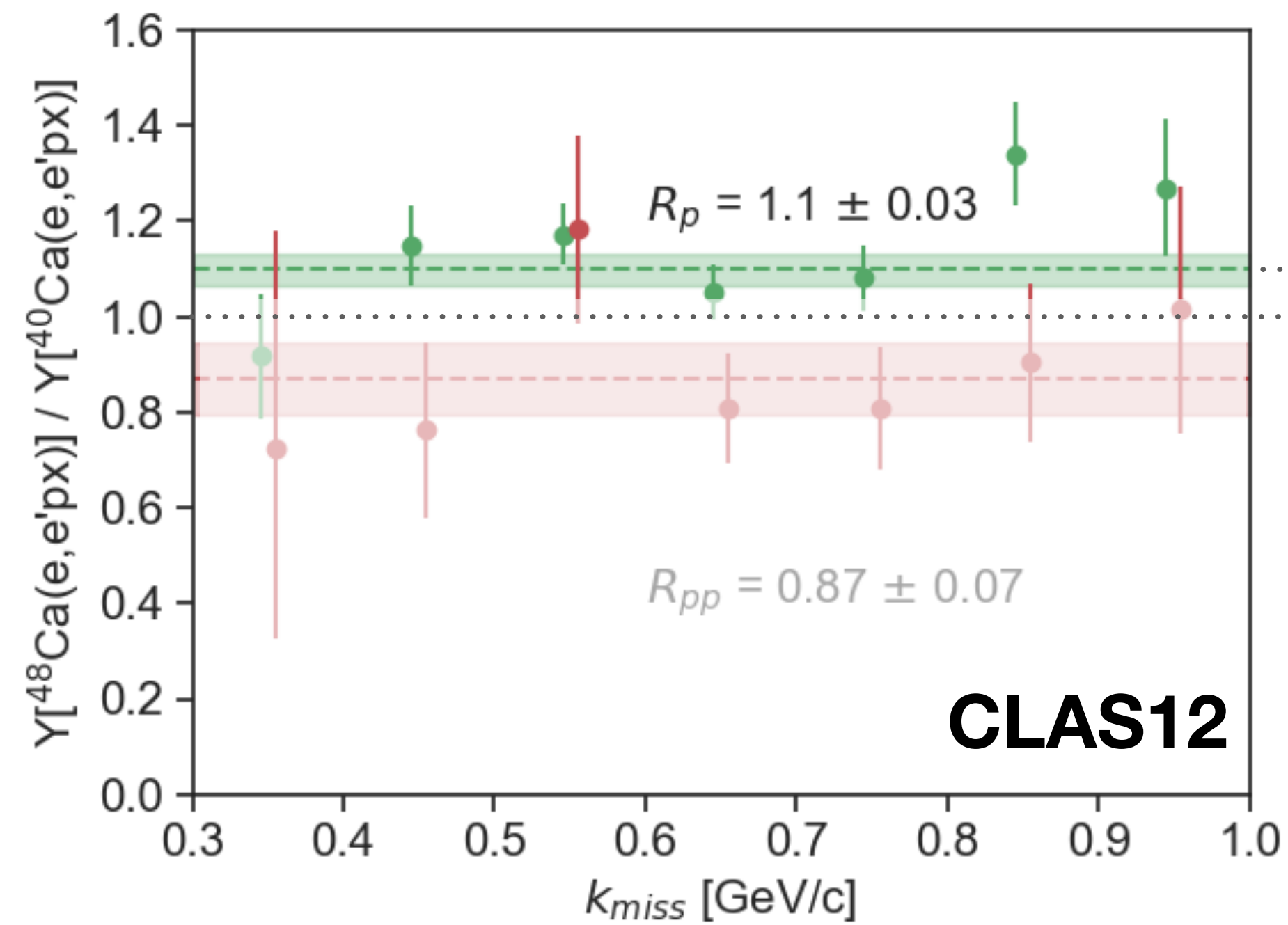
R. Yankovich et al., PRC 111 (2025)



SRC in ^{40}Ca & ^{48}Ca : $(e,e'p)$ and $(e,e'pp)$ at CLAS12 / JLab

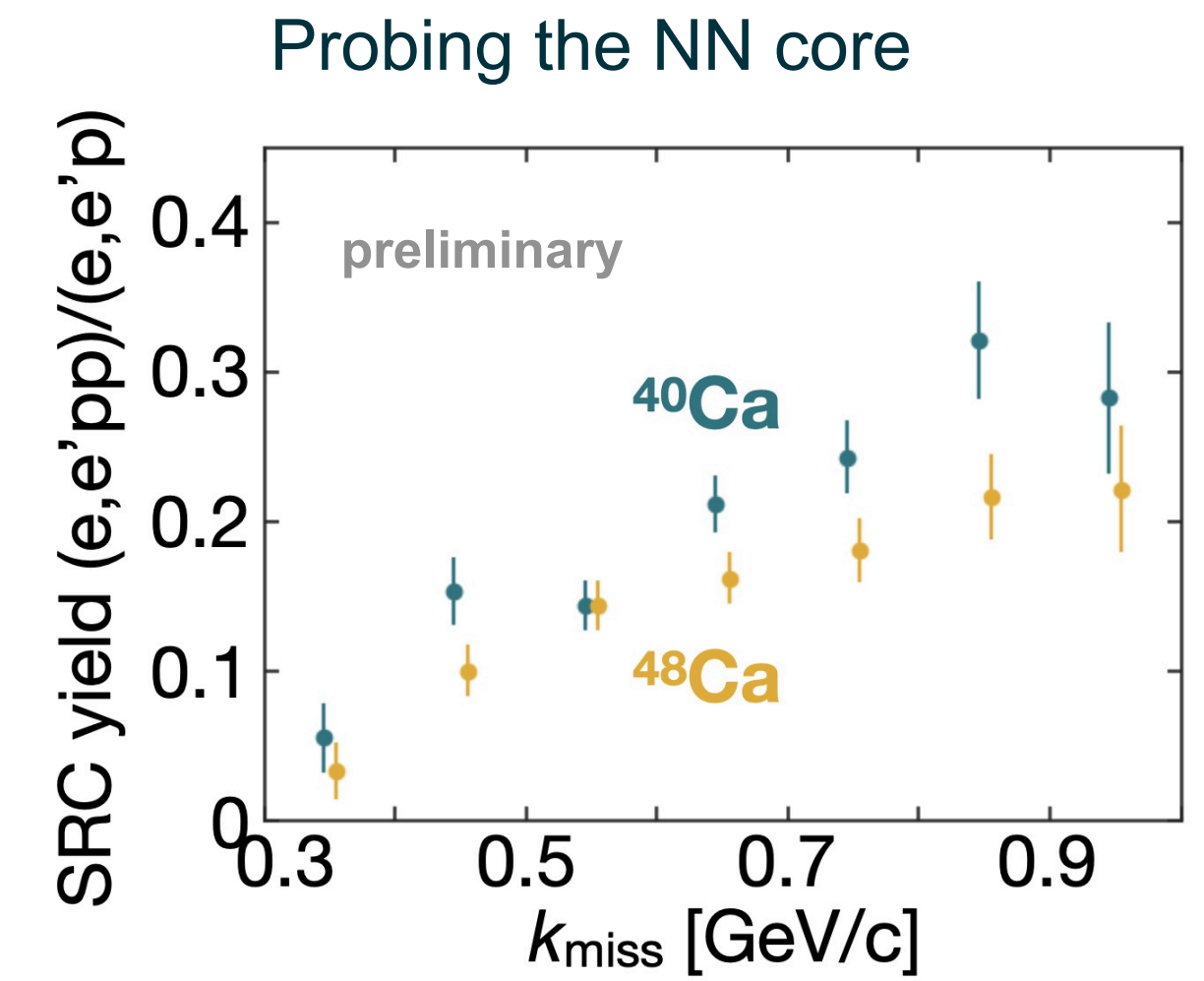
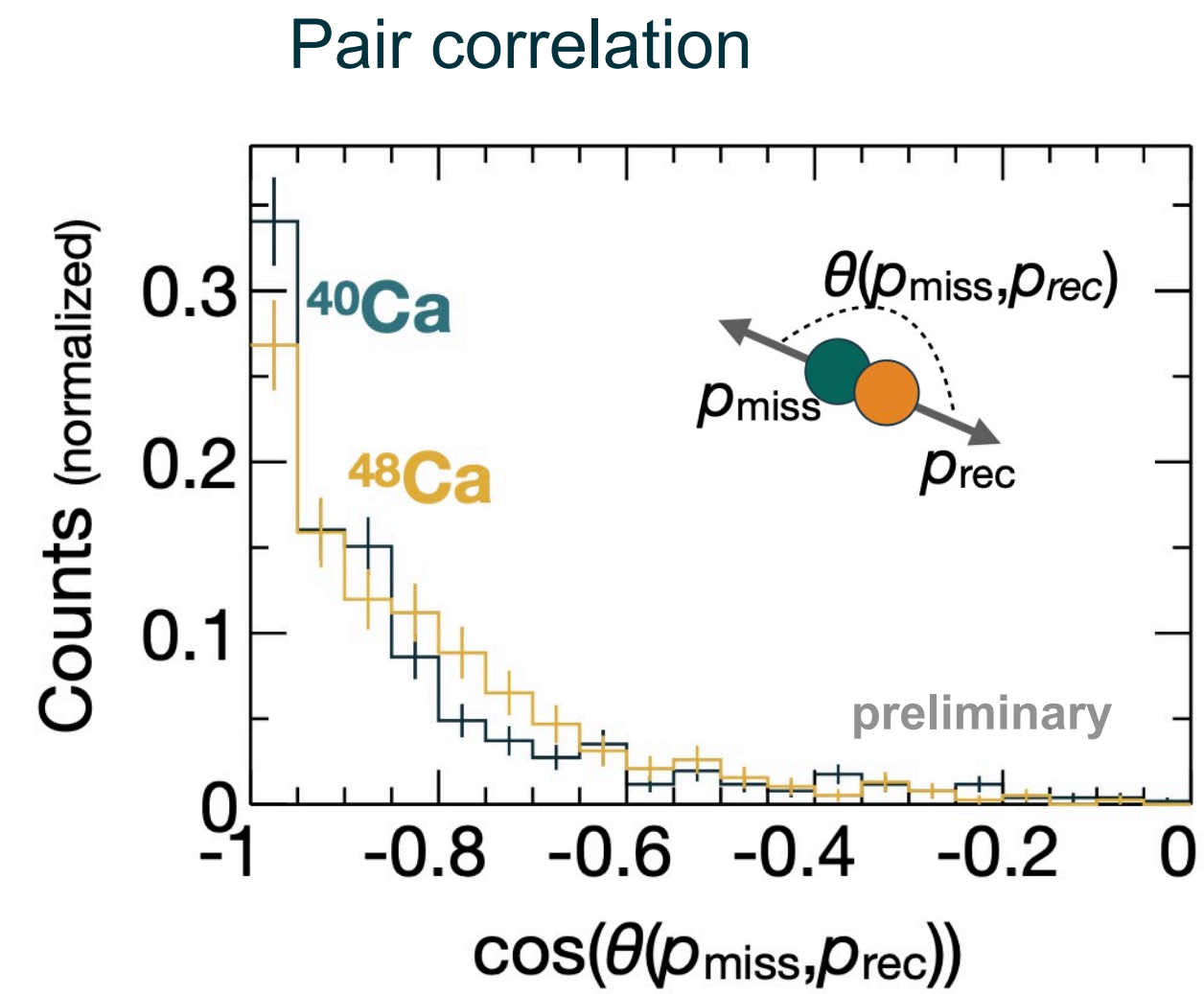
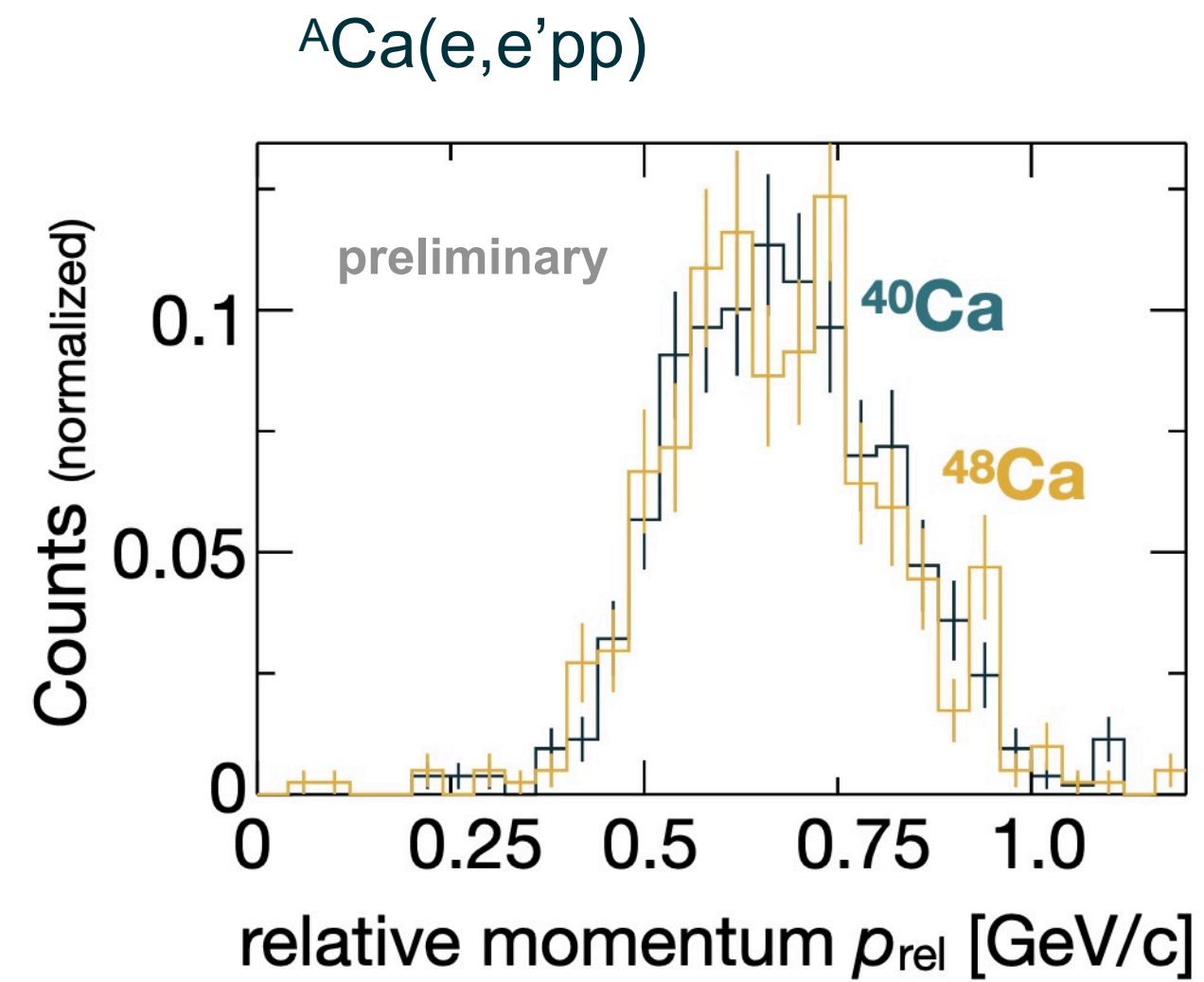
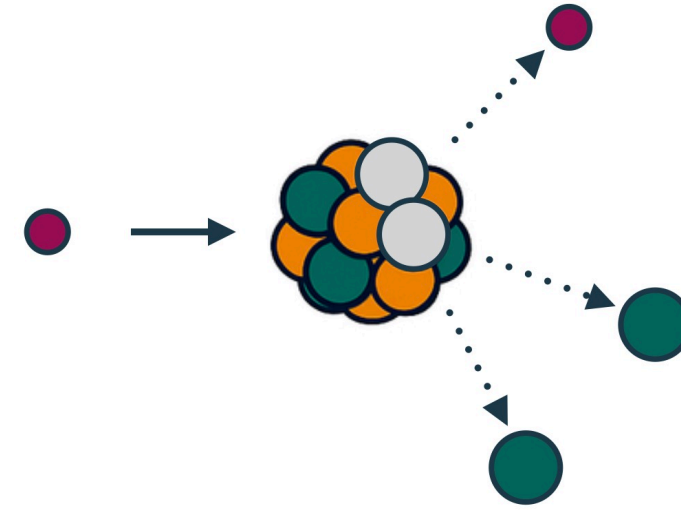


SRC in $^{48}\text{Ca}/^{40}\text{Ca}(e,e'p)$: CLAS12 = Hall C



- momentum transfer $Q^2 > 1.5 \text{ GeV}^2$
- Bjorken scaling $x_B > 1.2$
- struck p momentum: $p_{\text{lead}} > 1 \text{ GeV}/c$
- $0.65 < M_{\text{miss}} < 1.1 \text{ GeV}/c^2$
- recoil p momentum: $0.3 < p_{\text{rec}} < 1 \text{ GeV}/c$

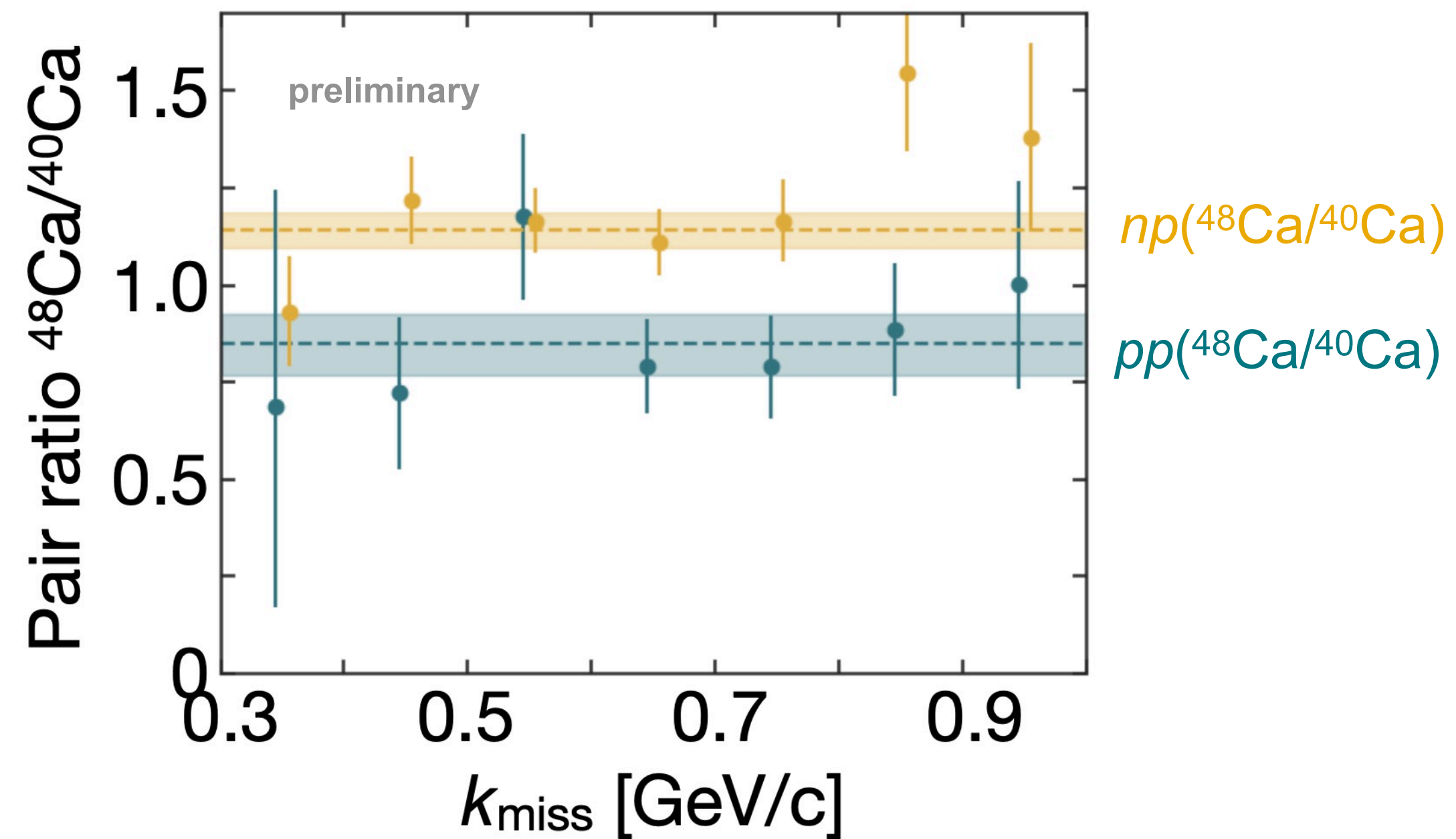
SRC in $^{48}\text{Ca}/^{40}\text{Ca}(e,e'pp)$



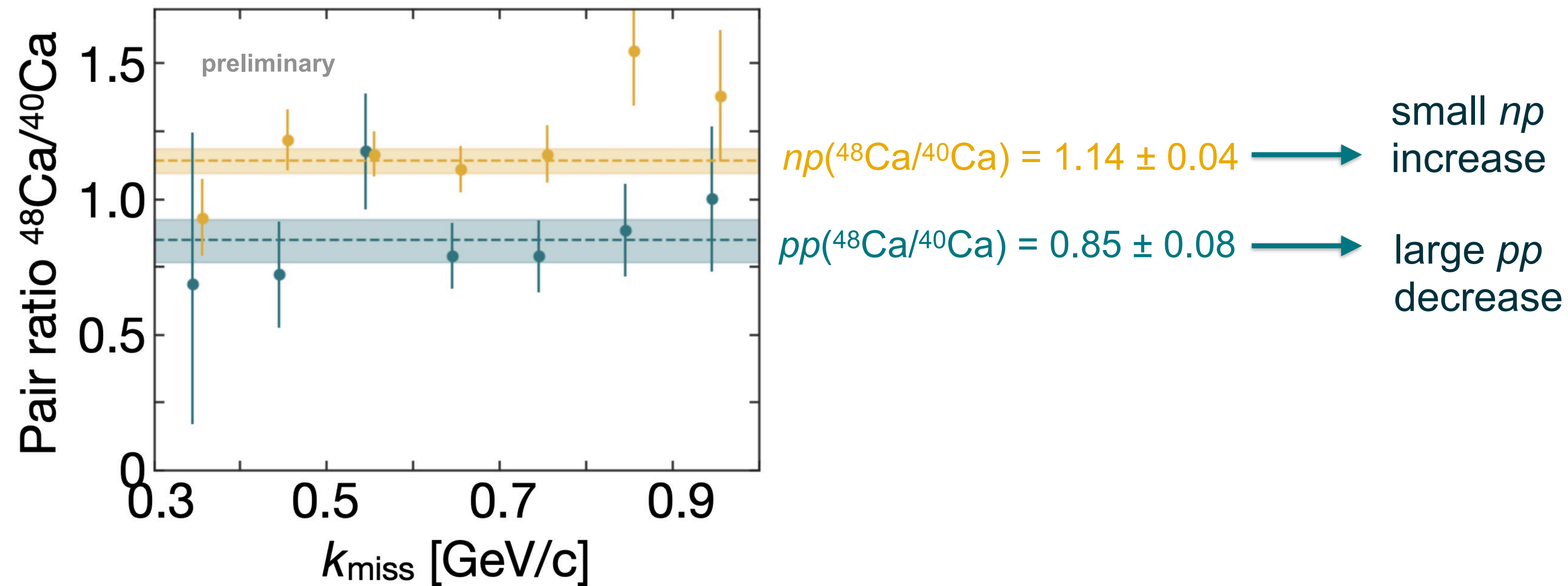
SRC np and pp ratios in $^{48}\text{Ca}/^{40}\text{Ca}$

$$(e, e'pp)_A \sim \#pp \cdot 2\sigma_p \cdot T_{pp} + \#np \cdot \sigma_n \cdot T_p T_r P$$

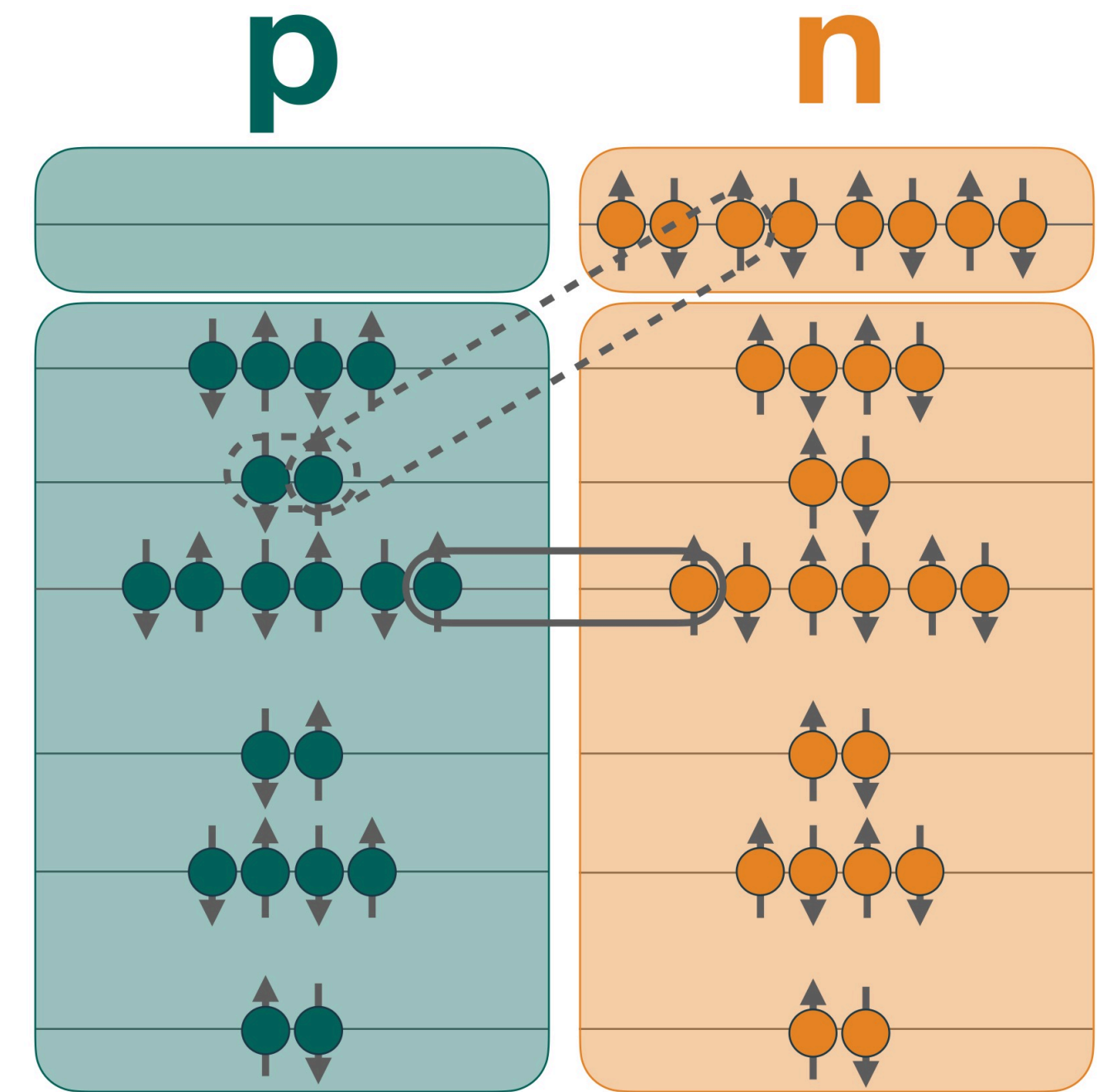
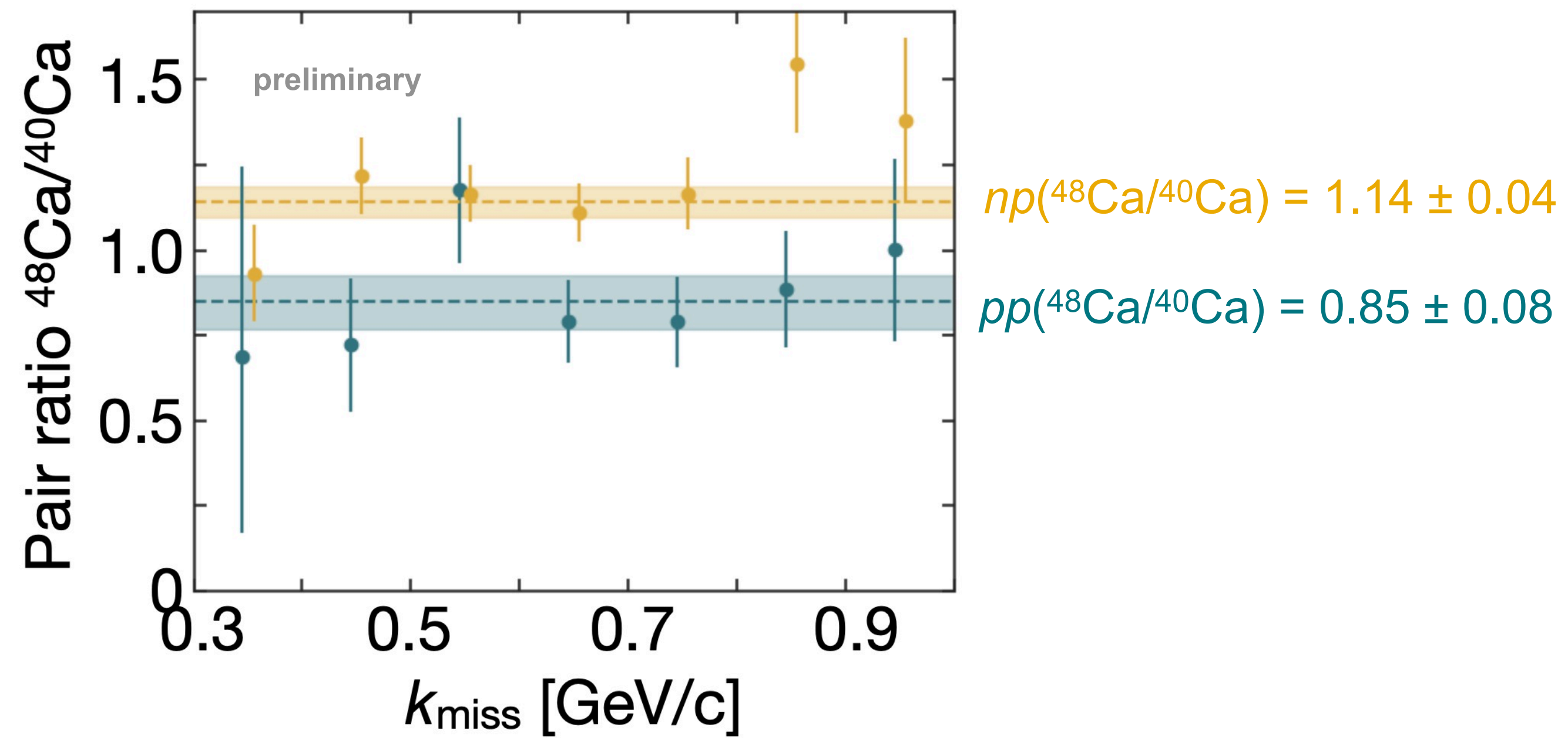
$$(e, e'p)_A \sim \#pp \cdot 2\sigma_p \cdot T_p + \#np \cdot \sigma_p \cdot T_p + \#np \cdot \sigma_n \cdot T_p P + \#nn \cdot 2\sigma_n \cdot T_p P$$



SRC np and pp ratios in $^{48}\text{Ca}/^{40}\text{Ca}$: This is surprising!



SRC np and pp ratios in $^{48}\text{Ca}/^{40}\text{Ca}$



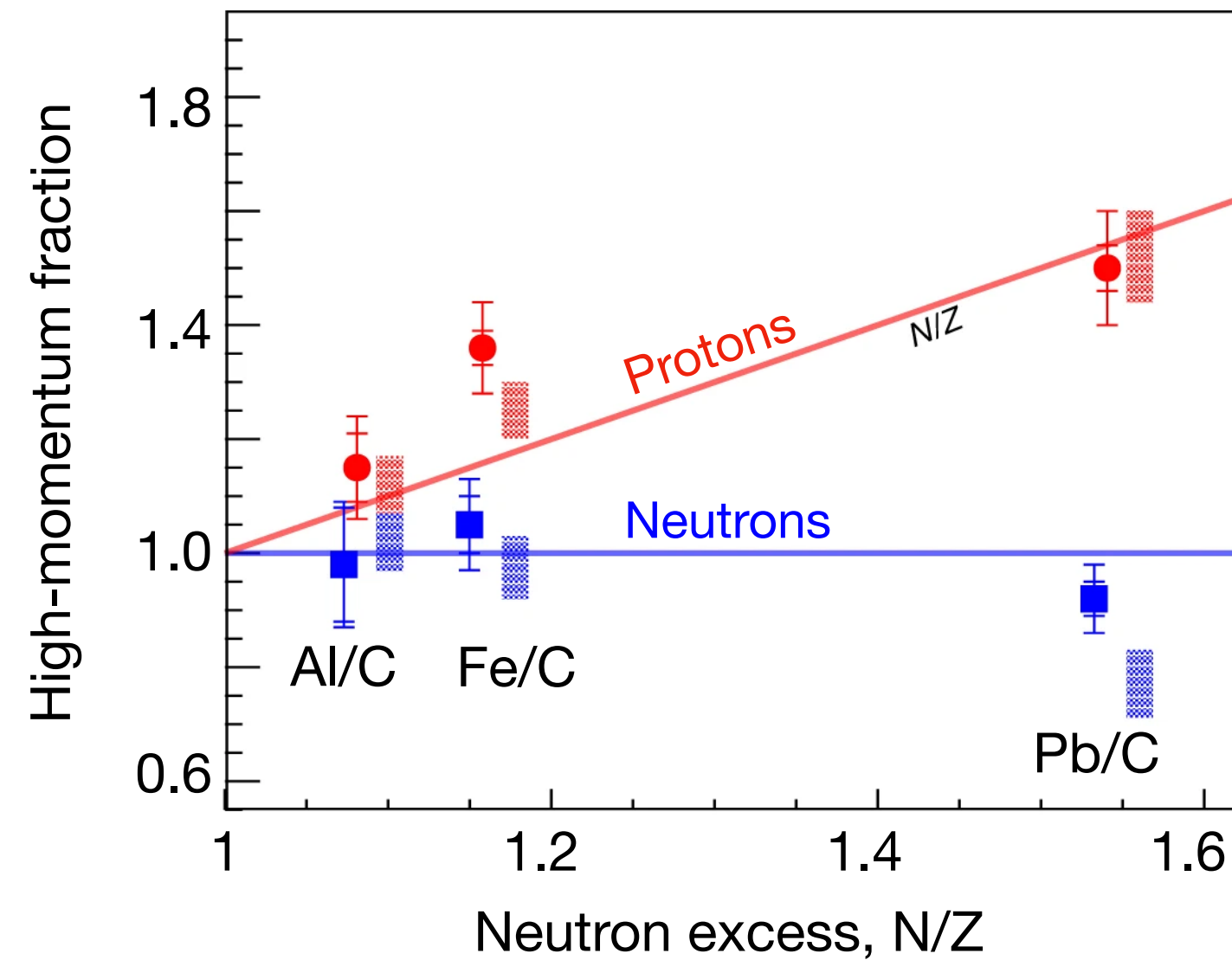
Summary

$^{40}\text{Ca} \rightarrow ^{48}\text{Ca}$:

Large increase in $f_{7/2}$ neutrons causes only small increase in SRC np pairs but large decrease in pp pairs

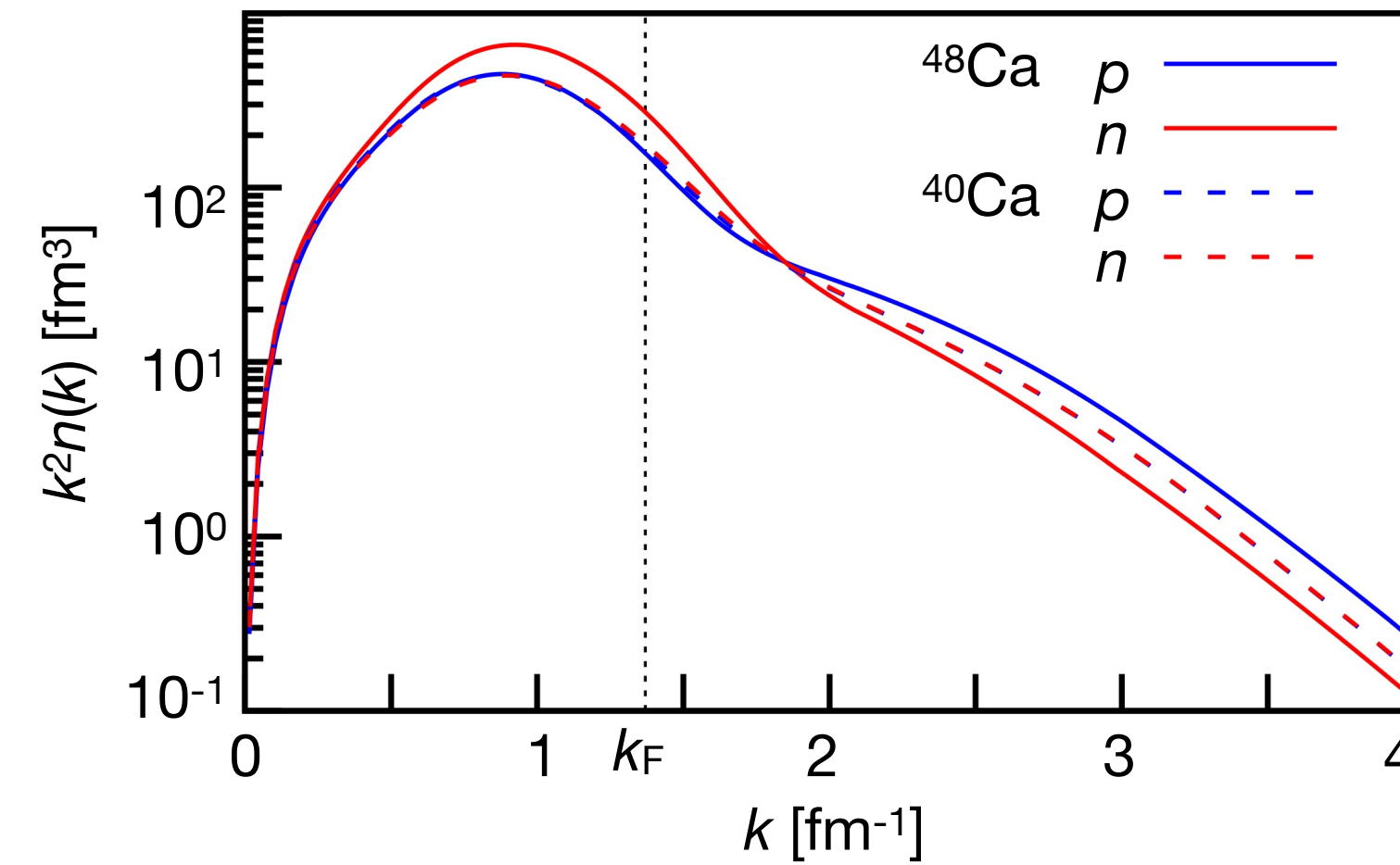
→ np pair formation beyond angular momentum quantum selection rules that pull protons from pp pairs ?

SRC properties and predictions



→ protons to be more correlated in n -rich nuclei

M. Duer et al. (CLAS), Nature 560 (2018)

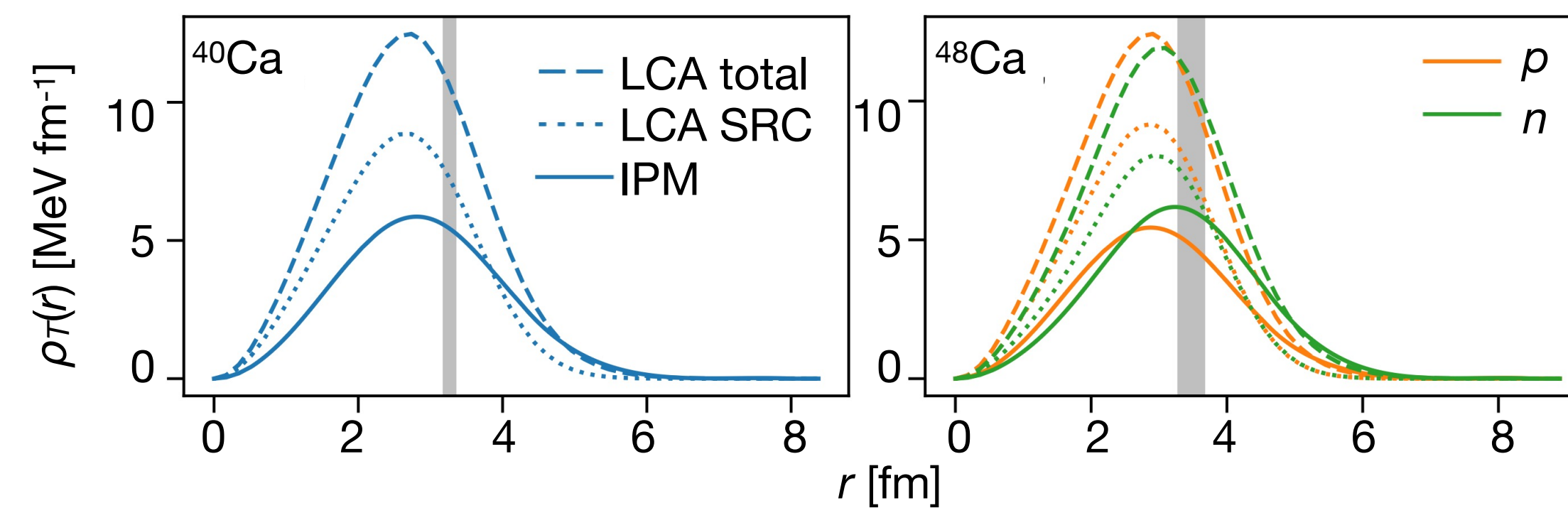


Dispersive Optical Model

→ more high-momentum proton content in $^{48}\text{Ca}/^{40}\text{Ca}$

M.C. Atkinson, W.H. Dickhoff, PLB 798 (2019)

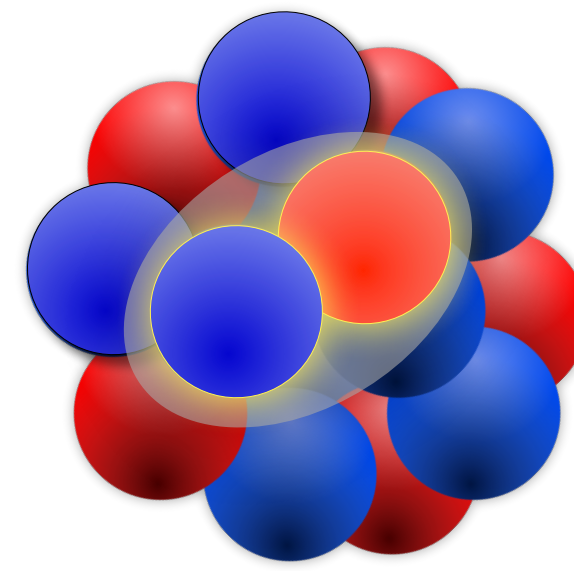
Lowest-order Correlation operator Approximation



→ SRC protons gain kinetic energy; concentrated in nuclear interior

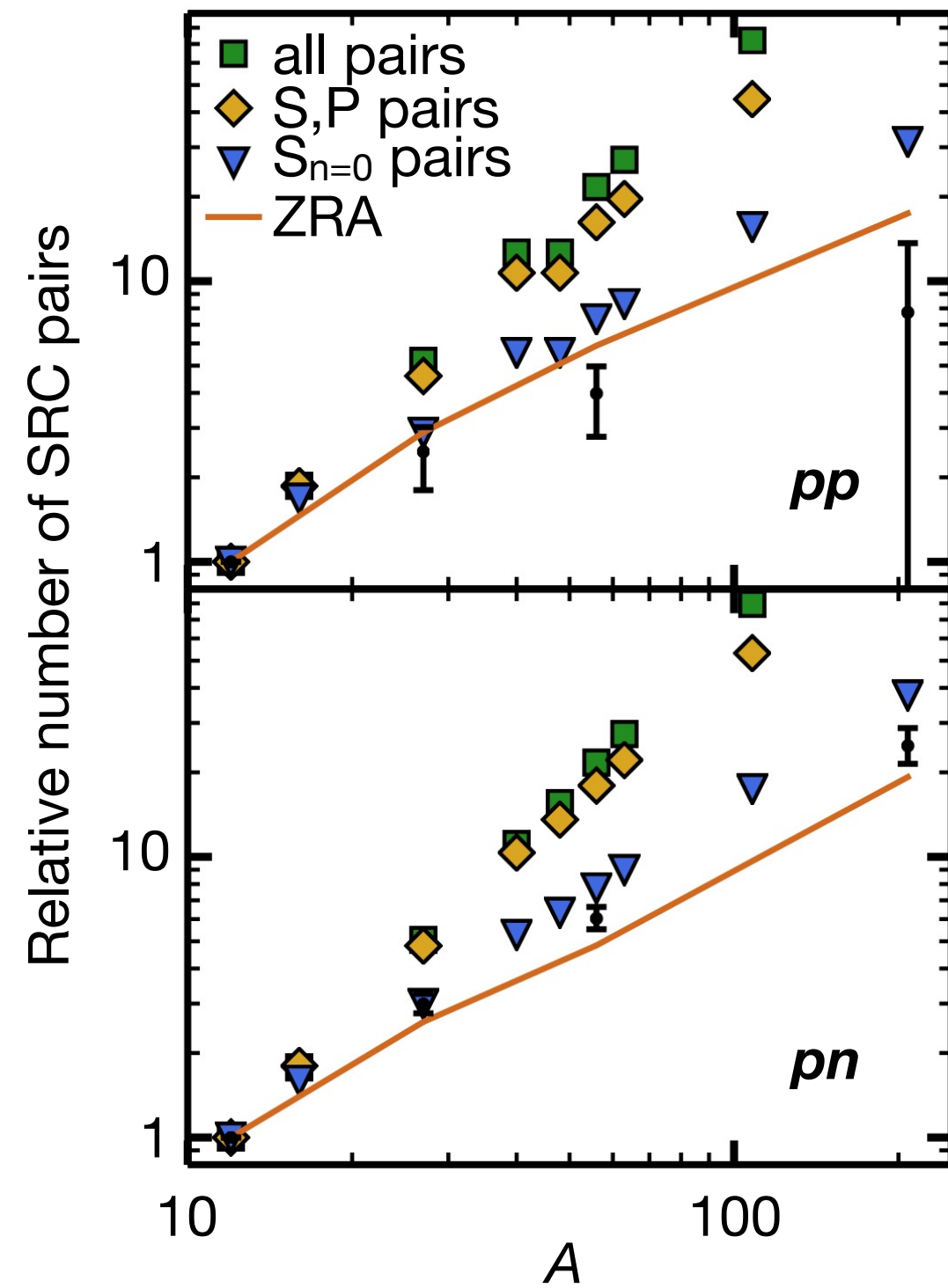
W. Cosyn, J. Ryckebusch, PLB 820 (2021)

SRC properties and predictions



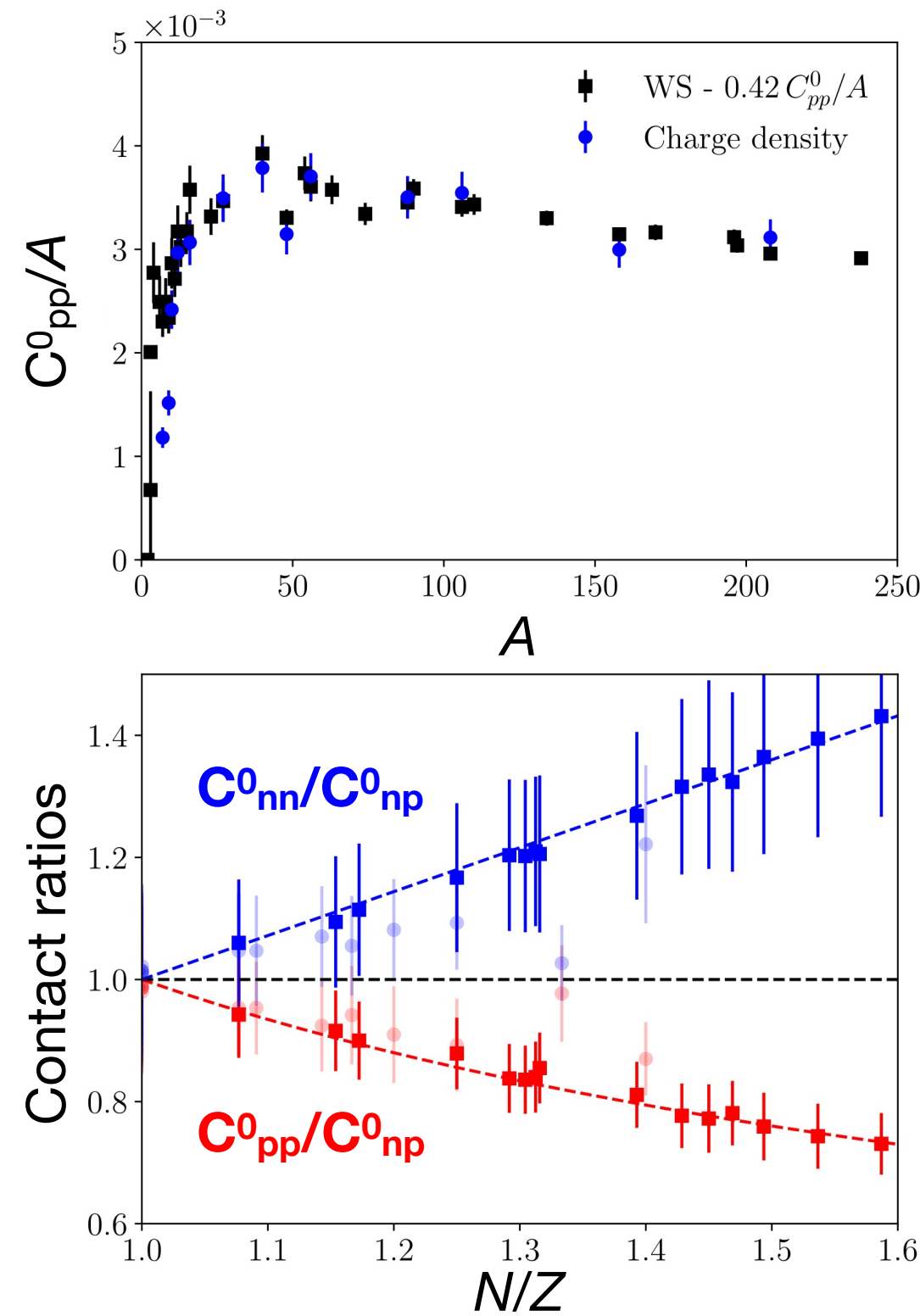
3S_1 np
 1S_0 pp, nn, np

C. Colle et al., PRC 92 (2015)



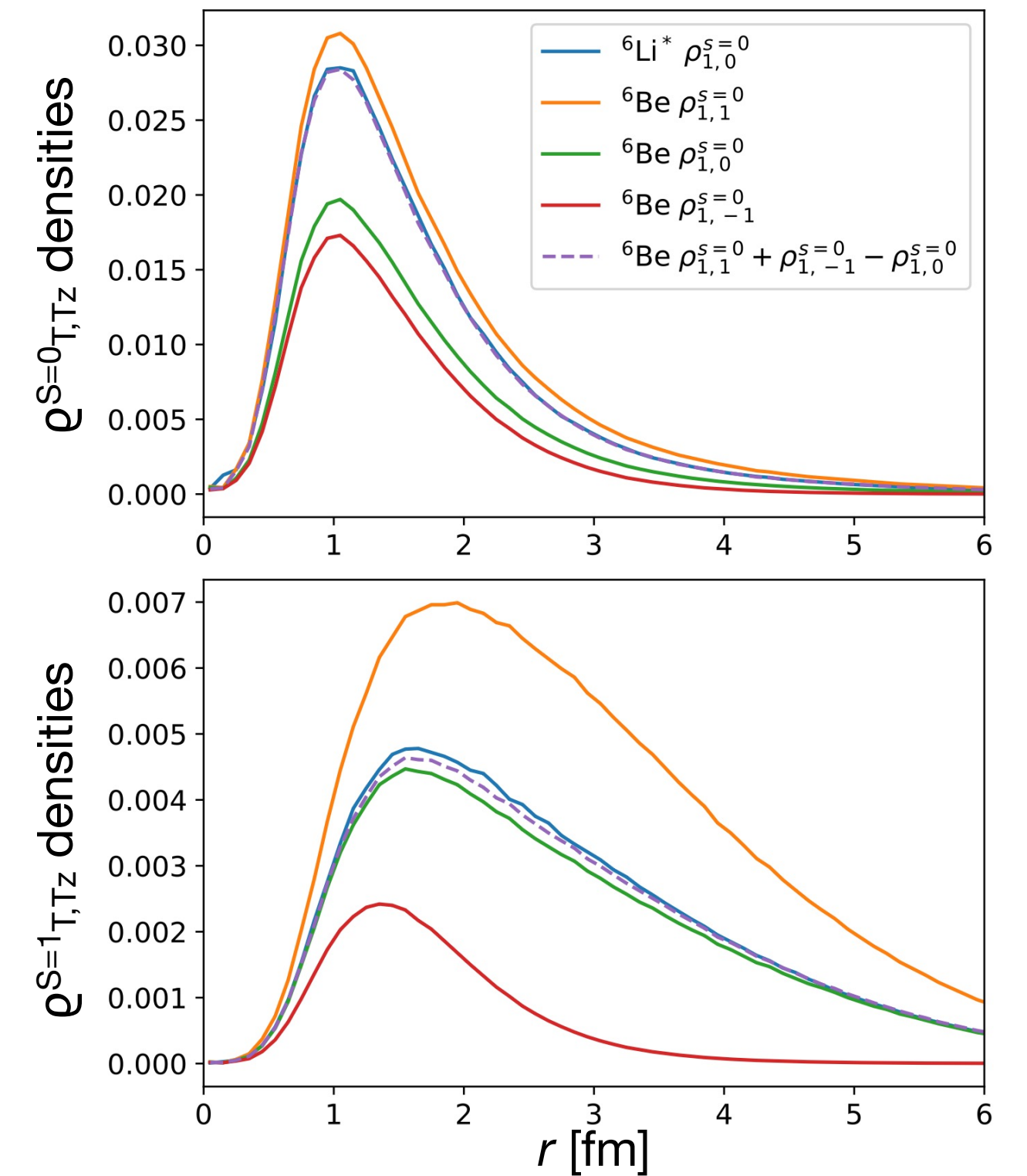
→ correlation operators acting on IPM $S_{n=0}$ pairs ($n=0$, rel. $l=0$) largely responsible for high-momentum nucleons

R. Yankovich et al., PRC 111 (2025)



→ WS spin-0 pairs ($n=0$, rel. $l=0$): pp pairs suppressed in heavy ($A > \sim 50$) and n -rich nuclei

R. Weiss et al., PRC 106 (2022)



→ VMC 2-body densities: spin-isospin selectivity through $A-2$ system

k_{miss} Cut Fourthly, we know that we expect SRC protons only above the Fermi momentum, so with a perfect detector we would place a cut requiring $0.4 < p_{miss} < 1.0 \text{ GeV}/c$ [4]. However, the momentum resolution of the CLAS12 detector is not perfect. Proxy variables for p_{miss} have been developed which utilized the high resolution of particle angles while making assumptions that the 2 nucleons in the SRC are on shell. The variable we will use is called k_{miss} .

$$k_{miss}^2 = m_N^2 \left(\frac{p_{miss,\perp}^2 + m_N^2}{p_{miss}^- (2m_N - p_{miss}^-)} \right) - m_N^2 \quad (3)$$

Where $p_{miss,\perp}$ is the component of \vec{p}_{miss} that is perpendicular to q and p_{miss}^- is the light cone variable with the z axis along q ($p_{miss}^- = e_{miss} - p_{miss,z}$). To demonstrate the utility of k_{miss} we have shown in Fig. 2 and . As we can see, there is a close correlation between k_{miss} and p_{miss} with k_{miss} being only slightly smaller in magnitude than p_{miss} . However, they cover nearly the same momentum range.